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ANALYSIS OF VERY FAST TRANSIENT OVER VOLTAGES IN GAS INSULATED SUBSTATION

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ABSTRACT

In a Gas Insulated Substaions (GIS), Very Fast Transient Over voltages (VFTOs) are generated mainly due to switching operations. The switching operation may be of a disconnector switch or a circuit breaker or an earthing switch. For Ultra High Voltage GIS, switching overvoltage levels are possible up to 3.0 p.u. depending on switching configuration and are comparable to basic insulation level. In other words, the margin between protection level and insulation level becomes narrow and reliability of equipment becomes a major concern. In view of this, overvoltage levels shall be controlled by means of suitable measures like control switching, switching through resistance etc. In the present study, very fast over voltages (VFTO) generated in a GIS are calculated for a 800 kV class GIS by considering standard configurations. IEEE Modeling of GIS components will be considered and the parameters which affect these over voltage levels will be analyzed as part of the study.

Keywords: Gas Insulated Substations, Modeling, VFTOS, Simulation, GIS,

I I INTRODUCTION

Insulation coordination is the coordination of electrical insulation levels with over voltage protection. Switching over voltage levels and their mitigation is one of the important studies of insulation co-ordination of gas insulated substations (GIS). In order to avoid insulation failure, the insulation level of different types of equipment connected to the system has to be higher than the magnitude of switching transient over voltages that appear on the system. The magnitudes of transient over-voltages are usually limited to a protective level by protective devices. The

characteristics of transient voltages and the characteristics of protective devices like surge arresters are to be determined as part of insulation coordination studies.

II. GENERATION OF VERY FAST TRANSIENTS OVER VOLTAGES (VFTOS)

Fast transient over voltages in GIS are mainly due to two reasons

1. Disconnector switch operation
2. Faults between bus bar and enclosure

In case of line-to-earth faults, the voltage collapse at the fault location occurs in a similar way as in disconnector gap during restriking. By this event, step shape-travelling surges are injected. When SF6 gas breakdown occurs, it extinguishes very quickly, since it has a high electro-negative property. Breakdown in SF6 starts initially by avalanche, starting with an initiatory electron due to cosmic radiation, field emission or several other phenomenon producing electrons. These electrons are accelerated by electric field, thereby increasing its kinetic energy. As a result, number of electrons increase due to collisions. According to streamer criteria, first avalanche occurs followed by chain of avalanches bridging the gap between the electrodes and thus forming the streamer. Thus, to have the breakdown there should be sufficient electric field to produce sequence of avalanches and there should be at least one primary electron to initiate first avalanche. In the above sequence of events, there exits a time lag for initiating electron to be available in the gap after the voltage is applied. This time lag is termed as statistical time lag. Similarly, the formation of spark channel takes definite time known as formative time lag which is of the order of nanoseconds for SF6 gas. The above phenomenon suggests that the VFTOS are generated due to the voltage collapse, which occurs in few nano seconds. Very fast transient over voltages (VFTOs) occur in Gas Insulated Substation (GIS) due to the operation of the disconnector switch. It has very short rise time of less than 5 nano seconds, and an oscillatory component of several MHz lasting for few microseconds. There are concerns about a possibility that the VFTOS sets of a resonance in the winding of the transformer in the system, particularly if the transformer is connected to the GIS through a gas insulated bus. The voltage oscillations in transformer winding have always been troublesome. Using the concept of 'on-resonance' or 'surge-proof' transformer, it is intended to suppress the oscillations by controlling the initial voltage distribution or capacitive voltage distribution. The device works against ordinary lighting impulses, but it may not necessarily be effective for oscillatory pulses such as VFTOs originated in GIS. It is of prime importance to investigate the underlying mechanism of VFTOs phenomena in the transformer and to provide a means to accurately predict the over voltages in the winding.

Two kinds of induced voltages are reported in transformers, one is high frequency component induced electro statically and the other is lower frequency component traveling along the winding. Initially this phenomenon was analyzed using simple ladder circuit network model.

They have showed that the inter turn voltage can be explained by a simple transmission line model. They have developed a generalized analytical method applying the single transmission line model. They have successfully applied this model to the VFTOs phenomena in transformer winding. Since the analysis requires a large scale computation, they have limited the computation area by the use of a terminal admittance representing the rest of the winding. Most of the time over-voltages cause a flashover from the winding to core or between the turns. The inter turn voltage is particularly vulnerable to the high frequency oscillation and therefore the study of over voltages is of interest. The VFTOS produced by switching in GIS depend not only on connection between the GIS and transformer, but also on the transformer parameters and type of the winding.

The basic function of disconnecting switches is to isolate sections of a GIS for ensuring safety of the operations. In the process of isolations, trapped charges may be left on certain sections of the GIS on

the capacitance to ground sections, resulting in large differential voltages across the disconnecting switches and also in the presence of AC-DC conditions across the poles of the switches. A switching operation such as re-energisation under such condition leads to switching charging current results in steeper oscillations which travel through the components of the system and suffer multiple reflections. These surges may cause internal flashovers to nearby grounded objects. Therefore over-voltages generated in GIS is a major parameter to be considered in insulation designs as it has bearing on many vital components of the installation such as insulating spacers, bushings, transformers etc. The electromagnetic interference (EMI) caused by over-voltages in electronic control circuitry is another problem to reckon with. For the above reasons, VFTOS generated in a GIS should be considered as an important factor in the insulation design. For designing a substation it is essential to know the maximum value of VFTOs. Moreover, this VFTOS in turn generates Transient Enclosure Voltages (TEV) outside the GIS therefore taking into consideration of these all factors and issues, the presented study in this thesis has been carried for the estimation of VFTOs as well as TEV levels

III SCHEME OF EVALUATION

A. Closing of a Disconnector

During the disconnector operation a number of pre or re-strikes occur due to the relative speed of the moving contacts [1]. During closing operation, the electric field between the contacts will rise still sparking occurs, the first strike occurs at the peak of the power frequency voltage. The current flows through the spark and charge the load to source voltage. The potential across the contacts falls and arc extinguishes.

B. Modeling of Gis

In modeling a component, accuracy has to be maintained. For a reliable simulation, accurate representation is needed. As the VFT has a travelling nature, in modeling every component is represented as the equivalent circuits of lumped and distributed parameter lines. Using surge impedance and propagation velocity these lines are represented. The values of surge impedance and propagation velocity can be obtained from the Inductance and Capacitance as shown from the equations below.

Surge Impedance $Z = \sqrt{\frac{L}{C}}$, ohm……… (1)

Velocity of propagation V = $\frac{1}{\sqrt{LC}}$ ……..... (2)

From these equations 1 and 2 each and every module is represented.

In 765kV GIS, a three and half circuit breaker system is considered as shown in fig1 [2]. It has 6 combinations of disconnector, circuit breaker and disconnector series. The first disconnector from the source on left side is operated for the transient analysis.

The modeling of each component in 765kV is as shown in table 1.

C. Trapped Charge

When a Disconnector switch is opened on a floating section of switch gear, which is on common mode of operation, a trapped charge may be left on the floating section. The potential caused by trapped charge will normally decay very slowly (hours to days) as a result of leakage through (or across) spacers. Large trapped charge is undesirable for several reasons. A trapped charge near 1p.u. (peak) can leviate particles. Particle motion under DC excitation is much severe than that of AC excitation and may lead to scattering of particles onto insulating surfaces. Such

particle motion leads to appreciable (μA) DC currents which will normally discharge the floating section in a relatively short time. A trapped charge of 1p.u. implies that the first breakdown upon closing the Disconnector switch will occur at 2p.u. across the switch contacts and may lead to conductor-to-ground over voltages of up to 2.5p.u. Thus the magnitude of trapped charge left after operation of a disconnect switch may be of some consequence to switchgear relatively [3].

In the figure 1, the disconnector near the source is operated for transient analysis. For this operation, 5 various locations has been considered, voltages at these locations are as shown in table 2 and 3. Analysis has been done for various variations such as XLPE cable termination, Gas Insulated Transmission Line, Overhead Transmission Line.

III. DISCONNECTOR DURING SPARKING

The behavior of spark in the disconnecting switch during closing was represented using an exponentially decaying resistance. The spark resistance is given by

$R=Ro\ e^{(-t/\tau)}$.....................(3)

Where, $Ro= 10^8$ ohm, t= formative time, τ= 1ns and 0.5ns

The voltage breakdown speed is determined by the formative time. It is defined as a period within which the breakdown voltage falls from 90 to 10% of its value, when the inter electrode resistance is reduce from a very high value to a very low value.

IV DISCUSSIONS

In 765kV, two different values of τ are used, they are τ=1ns and τ=0.5ns. The peak magnitudes of transients depends on the terminal components connected, these can be Overhead Transmission Line, Gas Insulated Transmission Line and XLPE cable termination. Voltages at various positions in the circuit are as shown in tables 2 and 3.

Table 2: Transient Voltages for XLPE Cable termination, Gas Insulated Transmission Line and Overhead transmission line for τ=1ns in 765kV GIS.

	Cable termination	Gas Insulated Line	Overhead Line
	V in kV(p.u)	V in kV(p.u)	V in kV(p.u)
P1	882(1.41)	1010(1.62)	1216(1.95)
P2	909(1.45)	985(1.56)	1222(1.96)
P3	1169(1.87)	1124(1.80)	1376(2.2)
P4	992(1.59)	1008(1.61)	1234(1.97)
P5	1006(1.61)	1056(1.67)	1225(1.96)

In the first case of τ=1ns a maximum value of 2.2 p.u is observed for Overhead Transmission Line. The magnitudes are found to be high in Overhead Transmission line and then in XLPE cable termination and Gas Insulated Transmission Line.

Table 3: Transient Voltages for XLPE Cable termination, Gas Insulated Transmission Line and Overhead transmission line for τ=0.5ns in 765kV GIS.

	Cable termination V in kV(p.u)	Gas insulated line V in kV(p.u)	Overhead line V in kV(p.u)
P1	981(1.53)	1127(1.75)	1339(2.08)
P2	1047(1.63)	1122(1.75)	1363(2.12)
P3	1240(1.93)	1233(1.92)	1501(2.34)
P4	1169(1.82)	1187(1.85)	1374(2.14)
P5	1162(1.81)	1233(1.92)	1413(2.19)

Table 3: Transient Voltages for XLPE Cable termination, Gas Insulated Transmission Line and Overhead transmission line for τ=0.5ns in 765kV GIS.

As two cases have been executed one for the τ for 1ns and 0.5ns, for these values of τ, formative time or the time of breakdown voltagesis about 16ns and another for approximately 8ns respectively. The voltage magnitudes of τ=1ns is less compared to τ=0.5ns. In the real time operation of 765kV GIS time of disconnector operation is approximately around 20ns.

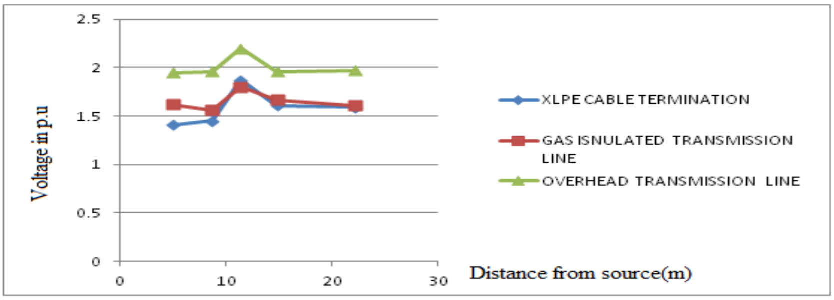


Figure 1: Comparision of Voltages for τ=1ns

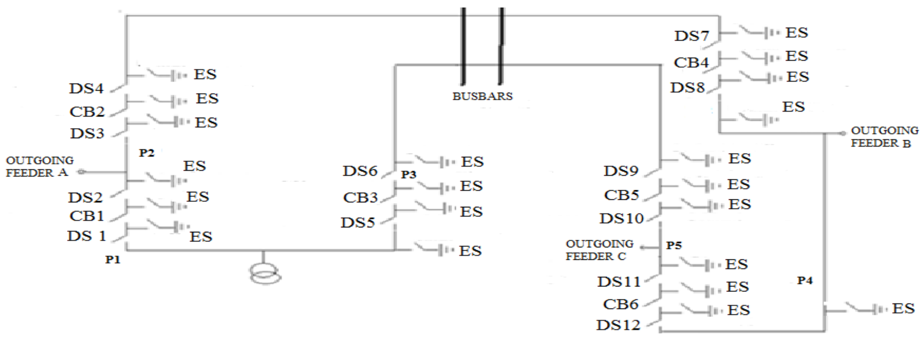


Fig 2: 765kV GIS Single Line Diagram

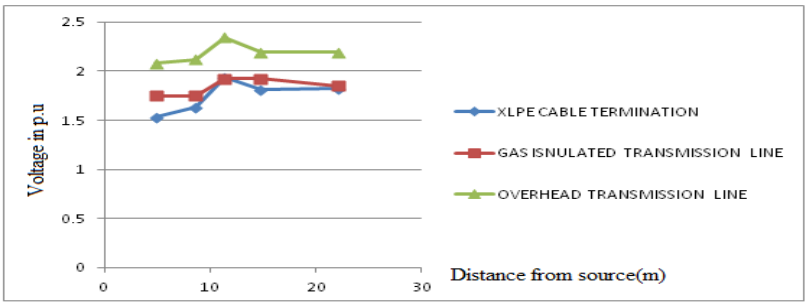
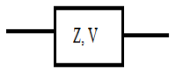
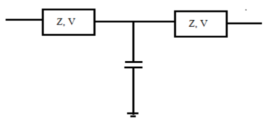
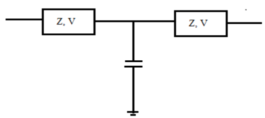
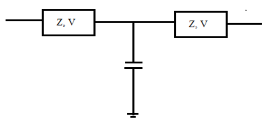
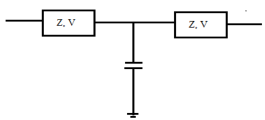
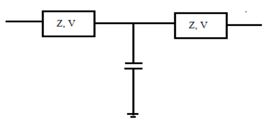
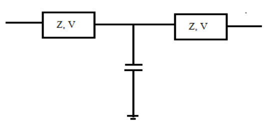


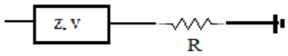
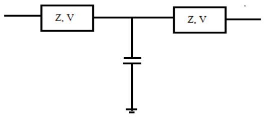
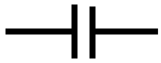
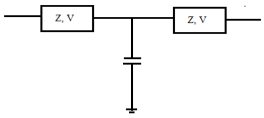
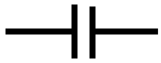
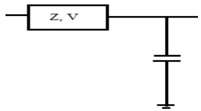
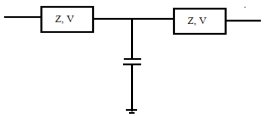
Figure 3: Comparision of voltages for τ=0.5ns

The maximum values of voltages is at the position 3, for τ=1ns is at a distance of 11.35m from the source, voltage value is about 2.2 p.u as the disconnector terminals are opened, and the minimum values of current is at this position itself, for τ=0.5ns is at a distance of 11.35m from the source, voltage value is about 2.34p.u. The magnitude of transient voltages in both the cases are high for Overhead transmission line as shown in figures 3 and 4

V. CONCLUSIONS

This paper 765kV Gas Insulated Substations has been modeled and analyzed for very fast Transient over voltages analysis. From the obtained results, maximum peak magnitudes of voltage are observed. While moving towards the systems, an overhead transmission line has maximum peak amplitude of 2.34p.u, with the change in the value of τ from 1ns to 0.5ns the peak magnitude varied from 2.2p.u, to 2.34p.u. The amount of transient voltage magnitudes in both the cases analyzed. Therefore, XLPE Cable termination and Gas Insulated Transmission Line are more preferred.

GIS COMPONENT	765kV GIS
BUS DUCT	 Z=63Ω, V=297m/μs
SPACER	 C=15pF
ELBOW	 C=15pF
SPHERICAL SHIELD	 C=15pF
SURGE ARRESTER	 C=19pF
CURRENT TRANSFORMER	 C=100pF
POWER TRANSFORMER	 C=5000pF

LONG TRANSMISSION LINE	 R=30, cable termination R=70, Gas Insulated Line R=350, Overhead line
DISCONNECTOR (CLOSED)	 C=240pF
DISCONNECTOR (OPEN)	 C=4pF
CIRCUIT BREAKER (CLOSED)	 C=350pF
CIRCUIT BREAKER(OPEN)	 C=4pF
GAS TO AIR BUSHING	 C=500pF
EARTHING SWITCH	 C=240pF

VI. ACKNOWLEDGEMENTS

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